INPUT TO THE FIVE-YEAR STRATEGIC PLAN FOR THE FEDERAL NETWORKING AND INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT PROGRAM

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Networking and Information Technology (NIT) is a dynamic field that transforms society, science and industry. It is not surprise that the center of gravity in this dynamic field continue shifting driven by changing societal challenges and emerging technological opportunities. I believe that we are in the right position now to identify, articulate and analyze the consequences of a new realignment in the field driven by the appearance of Cyber Physical Systems (CPS). In my input to the Federal Strategic Planning process, I intend to expose some elements of this new area and argue that the structure of the Federal NITRD investment need to be modified.

1 Future needs for NIT capabilities

NIT, once a provider of tools for the sciences and engineering, has become a uniquely interdisciplinary and pervasive field at the very core of the scientific and industrial innovation in the USA. We are surrounded by the results of a massive multidisciplinary R&D activity in such applications as analysis, and visualization capabilities for medical diagnosis; robotic exploration of Mars; computerized control in cars; international air-traffic control systems; computerized monitoring and control of industrial process. The "NIT explosion" is an auto-catalytic process, which simultaneously proceeds in many direction. The effects of this process are profound:

- The most exciting developments occur at the intersection of NIT with other areas. There are many examples for new science and technology fields, such as bioinformatics, smart materials, distributed robotics that turn into new disciplines and have the potential to jumpstart new industries.
- IT is becoming so pervasive that the classical structure of IT research and industry is changing drastically. For example, the tight integration of physical and information processes in embedded systems requires the development of a new systems science, which is simultaneously computational and physical. This ultimately leads to a new education and project management structure, which is very different from the existing models.

Arguably, the late eighties and early nineties were the "Big Bang" of IT. Triggered by the Strategic Computing Initiative of DARPA, Federal NIT investment created research breakthroughs in parallel and high performance computing. During the nineties, the center of transformational activity of NIT shifted to networking and the Internet. Starting from the mid-nineties, a new, less obvious, nevertheless perhaps the most pervasive expansion of NIT started emerging; the fusion of information processing with physical processes – called Cyber Physical Systems. CPS literally changes the physical world around us. From electric shavers to airplanes and from cars to factory robots, computers monitor and control our physical environment. NIT is rapidly taking over the role of being the universal system integrator for physical systems of all size. This trend is based on a fundamental technical reason: NIT is uniquely suited for implementing and controlling complex interactions among physical system components.

I believe that the deep integration of NIT with our physical environment will be the center of gravity of NIT in the next decade. This is a profound revolution that transforms entire industrial sectors into producers of cyber-physical systems. The deep integration is more than adding computing and communication equipment to conventional products where both sides maintain separate identities. The result is about creating new capabilities that fundamentally changes product capabilities and quality. CPS has extraordinary significance for the future of the U.S. industry. There is much more at stake than extending our leadership in NIT to an exploding new market segment. Falling behind in the foundations of CPS may render our scientific and technological infrastructure obsolete, leading to rapid loss in our competitiveness in major industrial segments including automotive, aerospace, defense, industrial automation, health/medical equipment, critical infrastructure and defense. We are in the midst of a pervasive, profound shift in the way humans engineer physical systems and manage their physical environment.

2 The Role of the NITRD Program

Federal investment in NITRD is particularly critical in periods of major transformations in technology. Federal investment has major role in stimulating basic research, attracting attention to solving fundamental challenges and helping the transformation of the research infrastructure.

I fully agree with the PCAST Report that the current prioritization of Federal NITRD does not reflect the fundamental shift in the center of gravity of NIT transformational activities. Roughly half of the federal dollars are invested in high performance computing (HEC I&A and HEC R&D), while CPS is not even represented as a crosscut.

I recommend changing this and - as recommended by PCAST - place CPS as first priority and Software as second priority for NITRD.

In order to increase the relevance of Federal NITRD in improving US Competitiveness, I have the following specific recommendations:

1. *CPS needs to be identified as a separate crosscut.* For example, this may happen by changing HCSS to CPS with a drastically extended role covering the full scope of CPS research. This is justified, since high-confidence system and software is essential and inherent part of the CPS research needs. While I was at DARPA between 1999 and 2002, I served as co-chair of SDP and saw clearly the significance of *clear and explicit* articulation of priorities. Without this change, NCO will not be able to coordinate CPS investment along a well defined research agenda.

2. The CPS research portfolio need to include cyber security and networking but driven by the specific needs and circumstances of cyber-physical integration.
3. The closest (although much narrower) existing crosscut, HCSS, receives 3.7% of the NITRD investment. This seems to be quite misaligned with the proposed priorities. Just to get in rough parity with the EU programs would require about $1B/ year investment in the area.
4. Software, which is currently included in the SDP crosscut, receives only 2.1% of the NITRD investment. The lack of investment in software research is a huge problem that impacts not only CPS but all NIT application areas.

3 Key Challenges for a CPS crosscut NITRD

As part of the community working on the formulation of a CPS research agenda, I concur with the main research challenges captured in the CPS Executive Summary Document[1]. The following table shows my perception about the relevance of the different areas to NITRD Agencies:

	New abstraction layers for design	**Semantic foundations for composing models**	**Composition platforms for heterogeneous systems**	**Predictability under limited compositionality**	**Foundation for system integration**	**Compositional certification**	**Agile design automation**	**Open Architectures**	**Reliable systems from unreliable components**	**Resiliency to cyber attacks**
NSF	■	■	■	■	■	■	■	■	■	■
DARPA	■	■	■	■	■	■	■	■	■	■
OSD and Services	■	■	■	■	■	■	■	■	■	■
DOE	■	■	■	■	■	○	○	■	■	■
NSA	□	□	■	■	□	□	□	■	■	■
NASA	■	■	■	■	■	■	■	■	■	□
NIST	■	■	□	□	□	■	■	■	■	■
AHRQ	○	○	□	○	○	■	○	■	○	■
DOE/NNSA	■	■	■	■	■	○	○	■	■	■
NOAA	○	○	□	○	○	○	○	□	□	○
EPA	○	○	□	○	□	○	○	□	□	○
NARA	○	○	○	○	○	○	○	○	○	○

(■: very important; □: important; ○: no information)

The strong overlap in relevance shows the importance of establishing interagency coordination.

[1] CPS Steering Group: Cyber-Physical Systems Executive Summary. March 6, 2008

4 Role of International Collaboration

NITRD is a worldwide enterprise and US is part of the international efforts. The chance for establishing substantial and mutually beneficial international collaboration and leverage large depends on the significance of the different areas on industrial competitiveness and national security. Not surprisingly, those NIT areas that are highly precompetitive and serve more the general scientific progress have a better chance for leveraging international efforts.

Based on this, my assessment for the areas where international collaboration is highly feasible and beneficial are: HEC I&A, HEC R&D, HCI & IM, and SEW.

The areas where some international collaboration in foundations are possible but direct relevance to competitiveness and national security decreases opportunity for leveraging investments are: HCSS, CSIA, LSN and ASDP.

CPS is clearly an area where the international competition is extremely high. For example, a declared goal of the Artemis program is to increase EU leadership in this area, therefore the research projects are tightly controlled and international collaboration is much harder. In certain basic research areas, such as Agile Design Automation or Resiliency to Cyber Attacks the mutual interests can be aligned for establishing collaborative programs, but the precondition for this is parity in investment.

5 Industry/Government/Academy Partnership and Technology Transitioning

A unique aspect of CPS is that the US Systems Industry (aerospace, automotive, process, automation, health energy, defense) recognizes the huge importance of the area in future competitiveness and expressed willingness to co-invest and create new partnership constructs. It is essential to ensure that a much tighter collaboration is created between industry and academia, where industry challenges more directly inspire research and academic solution are more easily validated in industrial strength testbeds. Willingness of industry and academia to create new forms of collaboration need to be exploited.